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Electron Spin Antiresonance in Magnetic Superlattices

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Abstract. We electrically detect the resonant absorption of microwaves by a two-dimensional electron gas modulated by a periodic magnetic field with zero average. The quantum interferences of two resonant spin flip transitions, one propelled by microwaves the other by snake orbits block spin flips hence the propagation of snake orbits. The resistance peak is found to be proportional to the probability of the hybrid quantum state produced by these interferences.

INTRODUCTION

Implementing quantum computation or giant magnetoresistance requires coherent spin dynamics. The traditional approach is to minimize decoherence by seeking materials with slow spin relaxation rate γ, for instance nuclear spin systems. An alternative route, which place less restriction on the range of suitable materials, is to increase the spin flip rate relative to the spin scattering rate. Huge Rabi frequencies are obtained by confining two-dimensional electrons in a canted magnetic field[1,2]. Magnetic edge states form at the lines of zero magnetic field. These snake states oscillate back and forth between positive and negative magnetic field domains subjecting the electron spin to a RF magnetic field of very large amplitude $(B_1 \sim 0.1T)$. The Rabi frequency $\Omega_1 = g\mu_B B_1 / \hbar$ is of the order of the GHz in GaAs/AlGaAs heterojunctions. This is 10^6 times larger than the Rabi frequency of microwaves produced by a typical backward wave oscillator outputting $1mW/cm^2$ of microwave power. Here we show that irradiating snake states with resonant microwaves exposes the electron spin to two competing spin flip transitions: one propelled by microwaves the other by the oscillatory motion of snake states. When both transitions are resonant, the initial states hybridize to form a dark state that blocks spin flips. The resistance exhibits an antiresonant peak caused by the freezing of snake orbits. This peak is labeled antiresonance because the microwave transition blocks spin flips when it is resonant with the snake orbit propelled transition.

EXPERIMENTAL

We fabricate a grating of cobalt stripes at the surface of a high mobility 2D electron gas (2DEG). The grating was magnetized by a homogeneous magnetic field B_a applied parallel to the plane of the 2DEG. This field set the Larmor precession of electron spins in the 2DEG but otherwise had no effect on the electron trajectories. The magnetic field was applied either along the long or the short axis of the stripes. When magnetized perpendicular to the stripes - full lines in Fig.1 - the grating applies a sinusoidal magnetic field of amplitude 0.14T and period 400nm. When magnetized along the long axis, the magnetic modulation is zero – dashed lines in Fig.1. The application of the magnetic modulation is demonstrated through the V-shaped magnetoresistance

(full lines). The V-shape is logically absent from the dashed line curve as no magnetic poles are formed.
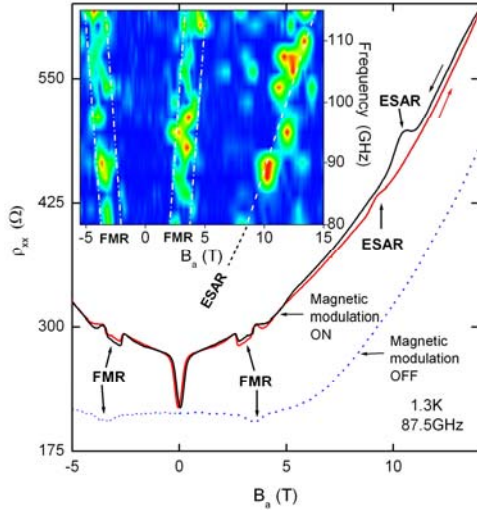
FIGURE 1. Magnetoresistance of a GaAs/AlGaAs 2DEG modulated by a sinusoidal magnetic field of amplitude 0.14T and period 400nm. The current is parallel to magnetic field domains. B_a is applied *in the plane* of the 2DEG either perpendicular to the cobalt stripes (magnetic modulation ON) or parallel to them (modulation OFF). Inset: frequency dependence of the ferromagnetic resonance (FMR) and electron spin antiresonance (ESAR). The slopes are inversely proportional to the Landé g-factor in the metal (g=2) and the GaAs quantum well (g^*=0.42).

Microwaves induce FerroMagnetic Resonance (FMR) at low field and Electron Spin Anti-Resonance (ESAR) at high field. Note that the ESAR peak disappears when the magnetic modulation is switched OFF (dashed lines). This is not too surprising as even though spin resonance is taking place, the 2DEG is in the ballistic regime with a constant density of states, unlike in previous experiments[3]. In this conditions spin flips do not lead to a net change in resistance and no peak is observed. The only qualitative change brought to the electronic structure by the magnetic modulation is the formation of snake orbits. Snake orbits form a bundle that covers a range of frequencies from zero to a few hundred GHz[1,2]. Those orbits whose frequency ω_1 matches the Larmor frequency ω_0 sustain spin resonance. Under microwave irradiation the electron spin is thus subject to the two transitions depicted in Fig.2(a).

INTERPRETATION

Given the strength of the time dependent magnetic field experienced within snake orbits, the condition of quantum coherence $\Omega_1 \approx \gamma$ is realized. Under double resonance, the initial states of the microwave transition and the snake oscillator driven transition couple through the final state. They hybridize to form a dark state in which the system eventually collapses. The dark state keeps the spin parallel or antiparallel under conditions of resonant absorption. Note that spin flips accompany the undulations of snake orbits. The blockade of spin flips freezes the propagation of snake orbits to give the ESAR peak in the resistance. We find that the thermal activation energy of the ESAR peak is precisely the Zeeman energy as if the Zeeman energy provides a barrier to the propagation of snake states. The ESAR peak is proportional to the probability of the dark state given by[4]:

$$P_{dark} = \frac{4\Omega_r^2\Omega_1^2}{\Omega_r^2 + \Omega_1^2} \frac{\Omega_1^2 + \gamma^2}{\left|\Omega_1^2 + (\gamma - 2i\Delta)^2\right|^2} \quad (1)$$

where Ω_r is the Rabi frequency of the microwaves. Eq.1 fits the ESAR peak as shown in Fig.2(b). Double resonance in magnetic superlattices thus offers a new approach for coherent spin manipulation.
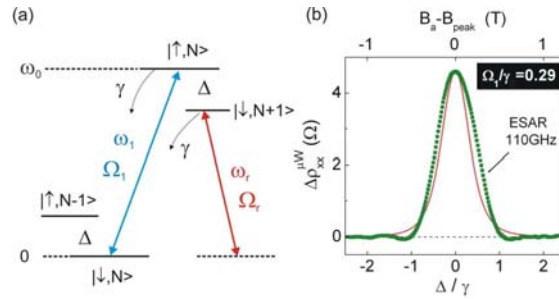
FIGURE 2. (a) Double spin resonance; (b) ESAR peak fitted with Eq.1.

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